Energy Efficient Data Centers

CONSULTANT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable and reliable energy services and products to the market place.

The PIER program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising, public interest energy organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Environmentally-Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Energy Systems Integration

What follows is the final report for the Energy Efficient Data Centers contract, contract number 500-01-024 conducted by the Lawrence Berkeley National Laboratory (LBNL). The report is entitled Energy Efficient Data Centers. This project contributes to the Industrial/Agricultural/Water End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Energy Commission Website http://www.energy.ca.gov/pier/reports.html or contact the Energy Commission at (916) 654 - 4628

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Executive Summary

Prior to this study, very little public information concerning the true electrical power requirements for California's data centers was available. This situation created much confusion, as data center developers claimed the need for large amounts of high-quality power – up to 250 Watts/square ft. To meet these requests, utilities receiving requests for new or upgraded service would have had to significantly upgrade the electrical infrastructure and/or provide for additional generating capacity. Uncertainty over electrical demand of present day and future information technology (IT) equipment led designers and operators of data centers to provide for unrealistically high electrical and HVAC system capacities. The Information Technology "industry" continually evolves and the prevailing wisdom was that the energy intensity of computing equipment would continue to rise, causing concern for the ability to provide cooling.

Prior case studies and limited investigation suggested that it should be possible to significantly improve the energy efficiency of data centers. To assist the PIER Industrial Program in identifying and prioritizing possible research areas, LBNL performed case studies involving six data centers and collaborated with various industry experts familiar with data center design and operation to develop a research agenda.

Project Objectives

The objectives of this project included:

- Obtaining measured energy end use energy efficiency information in 4-6 data centers, assembling additional data from synergistic projects sponsored by others, and using the case studies to help identify areas of potential public interest research.
- Characterizing the data center "market" in California
- Developing a research "roadmap" to guide California's public interest research on energy efficiency in data center facilities.

Project Outcomes

The project successfully arranged for data center's to be studied and obtained additional benchmarks beyond those originally planned. In all, benchmarks for sixteen data centers were obtained of which six were developed as part of this project. A key finding in the benchmarking results was that the average data center energy intensity today is on the order of 50 Watts/square ft. (compared to utility requests for up to 250 Watts/square ft.). Large variations in energy efficiency were also observed in the data center systems we studied, suggesting that there is room for significant improvement in data center performance using currently available technologies (such as improved chilled water system design or use of efficient air handlers instead of specialized computer room air conditioners. Individual case study reports were prepared for each of the six centers as well as for most of the other synergistic case studies. These reports included a number of energy efficiency recommendations.

The market characterization task was challenging in that no market data exists concerning the number, location, or size of many types of data centers. Alternate methods of estimating the square footage of data centers were needed to try to bound the problem. Using estimated floor areas in combination with average measured energy intensities, an estimate of the total electrical demand in California in 2003 of between 250 and 375 MW was determined.

For the energy research roadmap, considerable interface with data center industry suppliers, owners, designers, and other researchers occurred. They provided valuable input, which coupled with observations from the case studies, led to a comprehensive public interest roadmap document. The roadmap is available from the LBNL data center energy efficiency website. (See http://datacenters.lbl.gov)

Figure 1. LBNL Data Center Energy Efficiency Website

Conclusions

The following conclusions can be drawn from this project:

- Little energy benchmark data exists for data center facilities.
- Energy intensities today are not as great as the industry would lead one to believe; results ranged from 4 to 65 W/ft^2.
- Energy Efficiency opportunities given today's technology are numerous.

- As a result of IT equipment loads continually changing, special considerations allowing for the large potential variations in loads are necessary for data center infrastructure systems to be energy efficient.
- Data Center industry professionals often lack knowledge of energy efficiency opportunities, but are eager to find solutions.
- Reliability and availability are key concerns – to be embraced, energy efficiency must align with them.
- Large energy savings should be attainable through further research and development.

Recommendations

We recommend that the PIER Industrial program adopt the roadmap for energy efficiency public interest research in data center facilities. High priority activities, if pursued, could yield near term savings while contributing to a longer-term integrated strategy. Industry estimates indicate that over 50% energy savings over current practice is possible. With the large and growing number of data center facilities in California, a permanent reduction of electrical demand would prevent or postpone utility expansions, improve reliability, and provide bottom-line savings to every industry that relies on data centers in its business.

Benefits to California

The case studies performed during this project have provided the data center owners with a clear understanding of their energy use and are likely to spawn energy efficiency improvement projects at the facilities that were studied. But a broader group of data center professionals were also exposed to the results of the studies through workshops and industry events. This has created increased industry awareness and has started dialogue within data center owners and designers, which will be very beneficial.

The High Performance Data Centers research roadmap provides the PIER program with much needed understanding of how the data center industry views needed research and its priority. The PIER Industrial Program will be able to utilize the roadmap to plan a strategy to aggressively make improvements in this critical market sector. The roadmap will also facilitate collaborations with other energy research and industry organizations thereby leveraging public sector efforts in California.

Abstract

Data Center facilities, prevalent in many industries and institutions are essential to California's economy. Energy intensive data centers are crucial to California's industries, and many other institutions (such as universities) in the state, and they play an important role in the constantly evolving communications industry. To better understand the impact of the energy requirements and energy efficiency improvement potential in these facilities, the California Energy Commission's PIER Industrial Program initiated this project with two primary focus areas: First, to characterize current data center electricity use; and secondly, to develop a research "roadmap" defining and prioritizing possible future public interest research and deployment efforts that would improve energy efficiency.

Although there are many opinions concerning the energy intensity of data centers and the aggregate effect on California's electrical power systems, there is very little publicly available information. Through this project, actual energy consumption at its end use was measured in a number of data centers. This benchmark data was documented in case study reports, along with site-specific energy efficiency recommendations. Additionally, other data center energy benchmarks were obtained through synergistic projects, prior PG&E studies, and industry contacts. In total, energy benchmarks for sixteen data centers were obtained.

For this project, a broad definition of "data center" was adopted which included internet hosting, corporate, institutional, governmental, educational and other miscellaneous data centers. Typically these facilities require specialized infrastructure to provide high quality power and cooling for IT equipment. All of these data center types were considered in the development of an estimate of the total power consumption in California.

Finally, a research "roadmap" was developed through extensive participation with data center professionals, examination of case study findings, and participation in data center industry meetings and workshops. Industry partners enthusiastically provided valuable insight into current practice, and helped to identify areas where additional public interest research could lead to significant efficiency improvement. This helped to define and prioritize the research agenda. The interaction involved industry representatives with expertise in all aspects of data center facilities, including specialized facility infrastructure systems and computing equipment. In addition to the input obtained through industry workshops, LBNL's participation in a three-day, comprehensive design "charrette" hosted by the Rocky Mountain Institute (RMI) yielded a number of innovative ideas for future research.

The Data Center Case Studies, the California Load Characterization Report, and the Energy Research Roadmap were completed and are attached as appendices to this report. They are also available through the LBNL Data Center website, http://datacenters.lbl.gov/ along with other reference information.

1.0 Introduction

Background

Data Centers have long been an important component of California's industries, research organizations, educational facilities, and government. They are prevalent in both public and private-sector buildings serving many growing sectors of California's economy. Years ago, Data Centers containing mainframe computers were known to be very energy intensive (compounded by the associated high demands for air conditioning) requiring specialized infrastructure, but the development of the World Wide Web, and the shift to smaller, multiple-unit servers continued to utilize much of the same computer room infrastructure. Unfortunately, the continuous evolution of computing equipment creates uncertainty as to the overall energy intensity within data centers and the resulting demand on California's electrical power infrastructure. In the late 1990's, coincident with California's perceived energy crises, Internet hosting facilities were claiming that their infrastructure needed to support up to 200 Watts/square ft. and electric utilities even received requests for new power amounting up to 250 Watts/square ft. In some cases, in order to satisfy these requests, new power generation and/or transmission and distribution infrastructure would have been required raising issues of cost as well as complications of air-quality and power plant siting in urban areas. From California's public interest point of view, it was becoming very important to understand the patterns of energy consumption in data centers, and to be able to understand trends that could influence electrical load changes in the future.

Although the economic recession, beginning in 2001 in California, temporarily slowed and in some cases reversed growth in this market, the Information Technology (IT) industry continues to evolve. There is growing concern that technological advances are producing greater processing in smaller, more energy intensive devices. This simultaneously provides increased processing capability while complicating (or potentially making it impossible) to cool the devices. Energy efficiency improvements in servers and other IT equipment have not kept pace with the expanded processing capability. This situation has lead to several interesting scenarios involving growth in processing capability, and the increasing heat density trends in data centers. Some predict ever-increasing heat densities that eventually would force a change to liquid cooling. Other scenarios suggest that processing capability is outstripping demand and that this will result in compaction[1] and consolidation resulting in a reduction of cooling demands because in total, less computing equipment is needed. The case studies performed during this project identified evidence of both of these scenarios.

Prior investigations and anecdotal evidence suggested that there was considerable discrepancy between the electrical demand predicted when developers or building owners planned their data centers, and the actual measured electrical consumption. It

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[1] Large inefficient computers replaced with smaller computers having much greater computational capacity.

was felt that overstating the heat load resulting from IT equipment electrical loads combined with the use of inefficient or outdated cooling practices often resulted in over-sizing of HVAC systems and consequent inefficient operation.

Because some data center professionals believe that IT equipment's energy intensities will continue to increase, there also was a tendency to exaggerate the impact of these facilities on the electrical power grid within California. (See: http://n4e.lbl.gov/.) Electric utilities felt that requests for electrical service were unrealistic but had no hard evidence to suggest otherwise. To attempt to provide some insight into this situation, an estimate of the electrical power requirements for California's data centers was needed.

The PIER Industrial Program recognized that improving energy efficiency in data centers represented an attractive public interest research opportunity and wanted a plan developed that would identify various activities that could be undertaken. The plan (termed a "Research Roadmap") was to be developed with content and priority input provided by data center building professionals. Working with industry owners, designers, and operators, the "Roadmap" would guide energy efficiency research and its adoption into the marketplace. Recent slowdowns in the internet economy created a window of opportunity to begin developing solutions before the next cycle of explosive growth puts further strain on the California electricity grid.

Computer facilities have one thing in common - they are extremely energy intensive. The case studies performed by LBNL identified significant opportunities for energy efficiency improvement in these buildings through better application of existing technologies and development of new approaches. Numerous opportunities are apparent within the individual systems that support Data Center operations. Further investigation into the interface of building systems and computer arrangements (ie. servers, racks, mainframe computers, etc.) reveals even more savings opportunities. Additionally, within the IT equipment itself, additional opportunities exist such as placing components in "sleep mode", designing circuits that use less energy, more efficient processors, more efficient computer software, and others. All of these opportunities were explored during the development of the energy research roadmap.

The PIER Data Center work was also leveraged through other synergistic projects and collaborations at LBNL, including:

NYSERDA - Case studies and energy benchmarking for two data centers in New York, a paper on energy benchmarking in data centers for the ACEEE Industrial conference[2], and a workshop with the 7 X 24 Exchange Organization, NY Chapter[3].

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[2] See: Appendix XVIII, ACEEE 2003 paper #162, "Data Centers and Energy Use, Let's Look at the Data"

[3] See: Appendix XVII

Pacific Gas and Electric Company – Three prior case studies and energy benchmarking, and co-hosting a workshop with the Bay Area chapter of the 7 X 24 Exchange Organization (See: http://datacenters.lbl.gov.)

Industrial Partners – Many industrial partners provided in-kind support by providing input to the Data Center Energy Research Roadmap, and participating in the energy benchmarking.

Industry Associations – Informal collaboration with the Uptime Institute, the 7 X 24 Exchange Organization, a newly formed ASHRAE committee (TC 9.9) establishing standards for data center cooling, the CEETherm (a collaboration between the University of Maryland and Georgia Institute of Technology), and the Silicon Valley Manufacturers Group.

US Department of Energy – Federal Energy Management Program (FEMP) – Case studies and benchmarking for two federal data centers.

Prior work sponsored by the **US Environmental Protection Agency** including a report by Jennifer Mitchell-Jackson entitled Energy Needs in an Internet economy: A Closer Look at Data Centers. (See: http://enduse.lbl.gov/Info/datacenterreport.pdf.)

Rocky Mountain Institute (RMI) [Various Sponsors] – "Low Power Data Centers: Integrated Design Charrette", a collaboration of over 75 data center professionals and researchers.

1.1. Objectives

The objectives of this project were to advance the knowledge of energy use in data centers, estimate the electrical demand of these facilities in California, investigate energy efficiency opportunities, and develop a research agenda which could be adopted by the PIER program. The structure of the project consisted of two primary tasks:

- Data Center Load Characterization - which included the individual case studies and energy end-use benchmarking, as well as an estimate of data center market in California.
- Development of a Research Roadmap to identify and prioritize energy research, and deployment of new technologies and strategies to improve data center energy efficiency.

1.2. Report Organization

This report addresses each of the two major tasks. The Project Approach, Project Outcome, and Conclusions and Recommendations sections of the report each contain separate summaries of the respective tasks. A brief summary of the task activity is included, and the project deliverables are attached as appendices. The appendices generally provide greater detail of the task, the findings, and recommendations.

This report is organized as follows:

Section 1.0	Introduction
Section 2.0	Project Approach
Section 3.0	Project Outcomes
Section 4.0	Conclusions and Recommendations

There are 19 Appendices.

Appendix I "Estimating Total Power Used By Data Centers in California"; Jonathan G. Koomey, Osman Sezgen, and Robert Steinmetz, 2003

Appendix II. "Data Center Energy Characterization Study, Facility 1"; PG&E Case Study; Rumsey Engineers, Inc., 2001

Appendix III. "Data Center Energy Characterization Study, Facility 2"; PG&E Case Study, Rumsey Engineers, Inc., 2001

Appendix IV. "Data Center Energy Characterization Study, Facility 3"; PG&E Case Study, Rumsey Engineers, Inc., 2001

Appendix V. "Data Center Energy Benchmarking Case Study, Facility 4"; Federal Data Center Facility, Rumsey Engineers, Inc.; LBNL - TengFang Xu, 2003

Appendix VI. "Data Center Energy Benchmarking Case Study, Facility 5"; Federal Data Center Facility, Rumsey Engineers, Inc.; LBNL - TengFang Xu, 2003

Appendix VII. "Data Center Energy Benchmarking Case Study, Facility 6"; PIER Project, Rumsey Engineers, Inc.; LBNL – William Tschudi, 2003

Appendix VIII. "Data Center Energy Benchmarking Case Study, Facility 7"; PIER Project, Rumsey Engineers, Inc.; LBNL – William Tschudi, 2003

Appendix IX. "Data Center Energy Benchmarking Case Study, Facility 8"; PIER Project, Rumsey Engineers, Inc.; LBNL – William Tschudi, 2003

Appendix X. "Data Center Energy Benchmarking Case Study, Facility 9"; PIER Project, Rumsey Engineers, Inc.; LBNL – William Tschudi, 2003

Appendix XI. "NY Data Center Energy Benchmarking and Case Study, Facility 10"; NYSERDA Case Study, Syska & Hennessy; LBNL – William Tschudi, 2003

Appendix XII. "NY Data Center Energy Benchmarking and Case Study, Facility 11"; NYSERDA Case Study, Syska & Hennessy; LBNL – William Tschudi, 2003

Appendix XIII - “High-Performance Data Centers – a Research Roadmap”, Lawrence Berkeley National Laboratory Report No. 53483

Appendix XIV - RMI Charrette brochure, attendee list, and report.

Appendix XV - 8-22-02 Workshop Agenda, presentation, and meeting summary

Appendix XVI - 10-16-02 Workshop meeting notice and presentation

Appendix XVII - 4-17-03 Meeting notice and presentation

Appendix XVIII – ACEEE 2003 paper #162, “Data Centers and Energy Use – Let’s Look at the Data”

Appendix XIX – Annotated Bibliography

2.0 Project Approach

2.1. Data Center Electrical Load Characterization

Case Studies

Under this project, case studies were performed for six data centers in four very different organizations. For each, an energy end use breakdown was determined through actual energy measurement and analysis (benchmarking). The limited energy benchmark data were leveraged through other case studies performed through similar synergistic projects and by a leading data center industry association, the Uptime Institute. Each of the case studies provided potential energy efficiency improvement observations specific to the site.

To begin our investigation of the data center market in California, a sampling of various data centers were studied to determine their current energy use and the opportunity for energy efficiency improvement. First, the population of data centers to be included needed to be defined. For this project, a broad definition of a datacenter was adopted. This included various types of computing environments characterized by the requirement for specialized cooling systems and other specialized infrastructure such as raised floors, power conditioners, uninterruptible power supplies, etc. Using this definition, a number of industries such as Internet service providers were included as were most other industries that rely on large computing centers in their businesses such as banks, healthcare, etc. – virtually any large company. In addition, this market includes educational, governmental, research, and other institutions.

A diverse group of data center facilities were ultimately selected for the case studies and benchmarking. The participants included a computer disc drive manufacturer, an Internet hosting facility, a bank, and a California government facility. Two of the facilities had multiple data centers, which enabled two additional centers to be included within the project’s budget. At each site, meetings were held with the facility staff to describe the energy monitoring that would be required, and to collect any existing data along with selected design information. A subcontractor, Rumsey Engineers, then visited the sites to obtain energy end use data. The work at the facility generally occurred over a 3-5 day period depending upon constraints at the participating site. Where energy use information was available, such as direct readout from uninterruptible power supplies, it was recorded. In other situations, energy-monitoring equipment such as clamp on power meters was used to measure actual energy use. All energy use within the data center was accounted for resulting in a total energy end use breakdown such as shown in Figure 2.

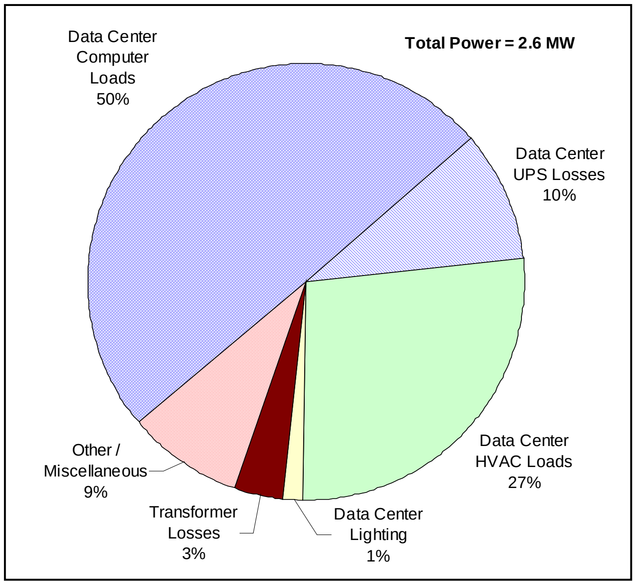


Figure 2. Representative Energy End Use From An Actual Case Study

In addition, the energy efficiency of key systems was determined. This generally included the HVAC chilled water system efficiency, the uninterruptible power supply (UPS) efficiency, transformer losses, etc. For HVAC, the metrics that were used provide benchmarks of the efficiency of making and delivering chilled water in terms of kW/ton. To calculate this metric, flow measurements were taken (or in some cases design data were used). To investigate the relative effectiveness of the HVAC systems in the various data centers, the ratio of HVAC power use to the total power consumption was determined. It was thought that a lower ratio may indicate a more energy efficient HVAC system, however other factors may also influence this. Efficiency of key electrical equipment (UPS, transformers, etc.) was determined by measuring input and output of the device.

It is common practice to express building electrical power requirements in terms of watts/square ft. (W/sf). To benchmark the relative energy intensity of the various load components in a data center, several different, and often confusing, building areas are used. These may include: gross area of the entire building, the area of raised floor, the area under computer racks, etc. To enable comparison of IT equipment's energy intensity to other industry data, we adopted the definition of "electrically active" space as defined by the Uptime Institute. This definition excludes support areas, storage areas, and major walkways thereby considering the energy intensity in the area where IT equipment is operating (generally, but not always on raised floors). This area data was obtained from design information and assistance from the host site. Using this area, an energy intensity of the "electrically active space" is developed since this is the area of interest that is housing IT equipment. Infrastructure support can likewise be expressed in terms of the energy intensity within this area.

Once data collection was complete, a site-specific report was prepared and then reviewed with the participant. These reports summarize the data collected and provide generic and specific recommendations for possible energy efficiency improvements. Generally, the reports are anonymous, as requested by the participating sites. Once the participant agreed with the content, the report was finalized and posted on the LBNL website: http://datacenters.lbl.gov.

2.2. Data Center Market Characterization

Characterizing the broadly defined "data center market" in California proved to be a daunting task. There currently is no comprehensive source of information concerning floor area or electrical demand for these facilities. Investigations with industry suppliers, designers, utilities, and other public sources of information yielded sketchy and unreliable data. For some types of centers, such as internet hosting facilities, prior industry studies, including real estate market estimates, were available and provided insight as to the size of that component of the market prior to the "dot com bust". For others, such as banks or educational facilities, little information exists. For these types of data centers, estimates were attempted through various means such as server shipments, or amount of raised floor sold, but ultimately these avenues were not useful. Eventually some estimates were determined through discussions with industry experts, or use of other parameters such as student count for educational institutions. These methods result in highly uncertain estimates. A report detailing the methodology for these estimates is attached as Appendix I. The report also provides a methodology for estimating data centers' contribution to electrical load broken down by the major public utilities in California.

2.3. High-performance Data Centers – a Research Roadmap

The philosophy employed in developing the research roadmap was to identify features of data centers where energy efficiency improvements were likely to be attainable through public interest research. These features were identified in a number of ways including LBNL observations during case study development, industry input through workshops, a charrette, individual consultation, participation in data center conferences, and interaction with industry associations and public interest organizations.

Early in the development of the roadmap, a workshop was held at the ACEEE summer study in Asilomar, CA with the goal of developing a framework for the roadmap. The meeting was held to capitalize on the fact that a number of leading energy experts were assembled, but was also well attended by some key industry experts. The meeting had key industry participation representing the design community; data center owners, energy engineers and consultants, and public goods program managers. Representatives of the following organizations provided input during this workshop:

AT&T
Pacific Gas and Electric
California Energy Commission
Southern California Edison
NYSERDA
ACEEE
Sure Power Corporation
Liebert Corporation
EYP Mission Critical Facilities
E-Source
Loudcloud
En-wise

The first workshop provided guidance for the project and a forum to identify barriers to efficient operation, areas of needed research, and other related research underway. The workshop agenda, LBNL presentation, and a summary of the workshop input are attached as Appendix XV. Following the workshop, LBNL developed the topic descriptions and suggested research areas in a first draft of the roadmap.

During the development of the roadmap, LBNL sought additional input from data center building design professionals, data center facility operators, and firms that provide specialty equipment such as computer room air conditioners. Additionally, research ideas were generated through informal collaborations with organizations such as the Uptime Institute (www.upsite.com), Intel Developers Forum, the 7 X 24 Exchange Organization (http://www.7x24exchange.org/), and CEETherm (see: http://www.me.gatech.edu/me/publicat/brochures/Mettl/Bro0302.htm). LBNL presented some of the preliminary project findings at the October 16, 2002 meeting of the Bay Area 7 X 24 Exchange Organization. Additional input was received at this meeting. A copy of the LBNL presentation and an unedited summary of the input are attached as Appendix XVI.

Once the first draft of the roadmap was developed, it was distributed to industry advisors for comment. LBNL further developed the roadmap topics through participation in a three-day charrette hosted by the Rocky Mountain Institute (RMI) where approximately 90 data center experts evaluated the energy efficiency potential and suggested numerous areas where current practice could be improved as well as where additional research could be expected to produce additional dramatic improvement. The RMI charrette brochure, attendee list, and charrette report is attached as Appendix XIV. The RMI report of the charrette was in preparation as of the completion of this project.

Finally, to further confirm the roadmap topics and to prioritize them, a workshop hosted by PG&E and the Bay Area chapter of the 7 X 24 Exchange Organization was held at the Pacific Energy Center on April 17, 2003. Benchmarking results were presented, and case studies were discussed including a detailed review of one case study (facility 8) presented by Rumsey Engineers. The attendees were then asked to provide input concerning the priority of research tasks identified in the roadmap. The presentations and unedited summary of the input is attached in Appendix XVII.

Following the workshop, the roadmap was finalized and submitted to the California Energy Commission. The final roadmap (LBNL report no. 53483) is attached as Appendix XIII, and is available on LBNL's website: http://datacenters.lbl.gov.

3.0 Project Outcomes

3.1. Data Center Electrical Load Characterization

Case Studies

Each of the anonymous case study reports is available through the LBNL website: http://datacenters.lbl.gov along with case study reports developed through synergistic projects. Attached with these reports, is a detailed, annotated reference list providing other useful information.

Summary comparison data for selected metrics was prepared and presented to various industry organizations such as the 7x24 Exchange Organization. The summary presentation material is attached as Appendix XVII. This included a comparison of energy intensity as measured during these case studies. See Figure 3 below.

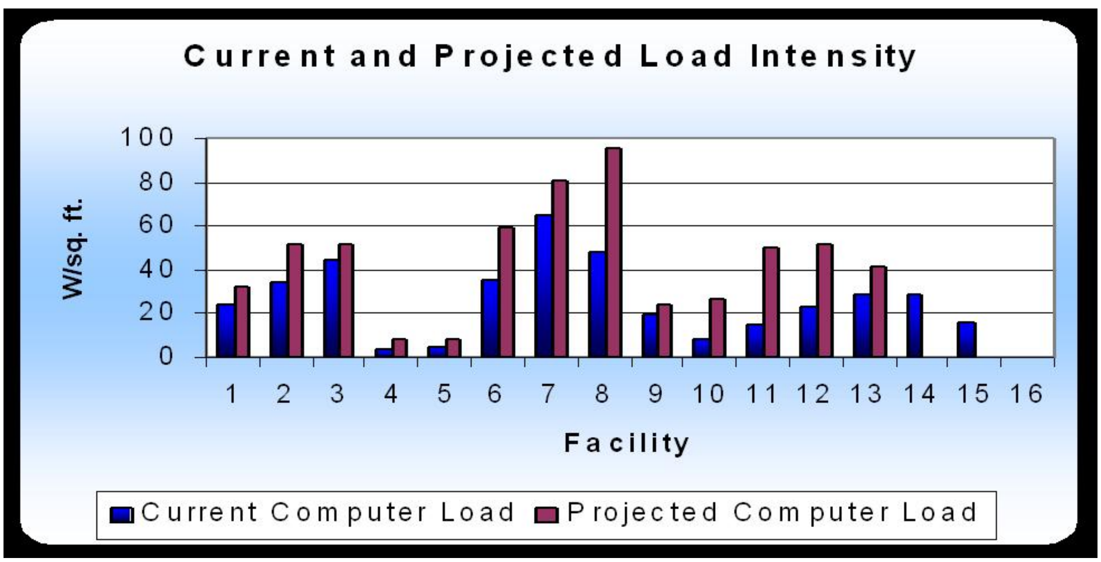
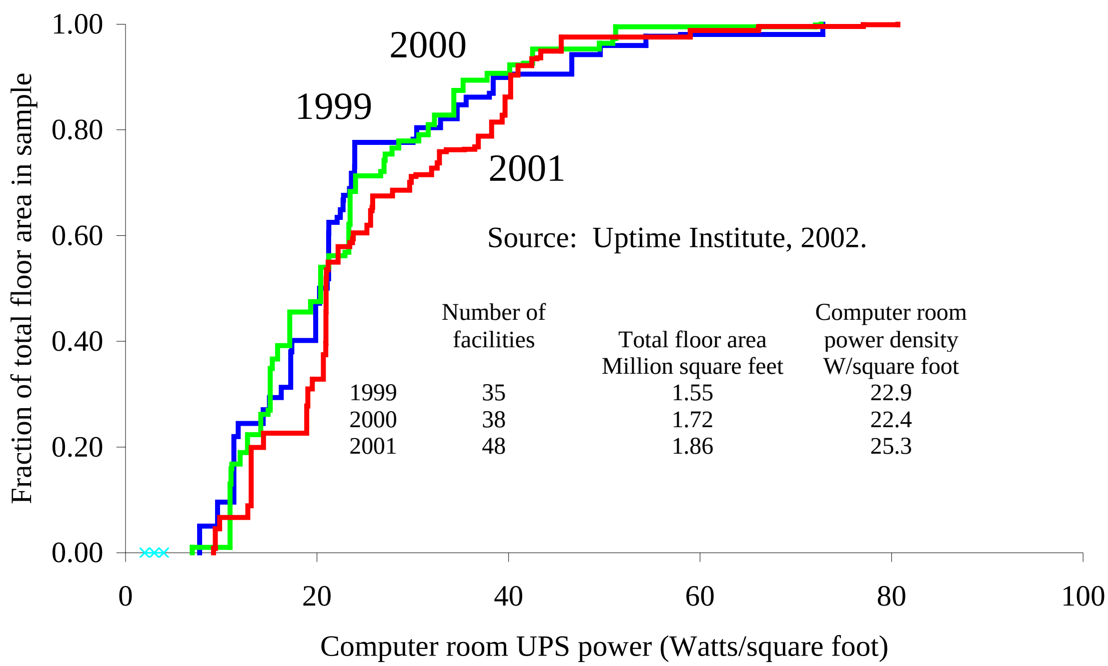


Figure 3. Measured and Projected Computer Load Intensity

Interestingly, these results demonstrated that the current average energy intensity of IT equipment in the measured data centers is approximately 25 Watts/SF. And, to project the intensity if the centers were full of similar equipment, the average intensity attributable to the IT equipment would only rise to approximately 40 Watts/SF. This combined with the other infrastructure loads (HVAC, electrical losses, etc.) is much below the power needs that the industry was claiming in requests to utilities. To investigate how this compared to other industry benchmarks, the Uptime Institute was contacted and provided energy data that their member companies provided over a three-year period. This information was summarized and the relative distribution of the reported energy intensity is provided below in Figure 4.



Source: Uptime Institute, 2002.

Figure 4. Cumulative Distribution Of Computer Power Densities (UPS Power)

This information agrees well with measured results in the case studies, indicating that average energy intensity for computing equipment in 2001 averaged approximately 25 Watts/SF. The data also indicates that there was little change in overall intensity during the three years reported.

Insight into the relative effectiveness of HVAC systems is provided through the ratio of HVAC power to total power as shown in figure 4. The large variation in performance suggests that some of the HVAC system designs were significantly more efficient than others. For example, a system that had a 20% ratio was presumably providing cooling more efficiently than a system with a 50% ratio, although other factors, such as the amount of office space, or type/sizing of UPS systems, may enter into this ratio. To fully investigate whether the HVAC system was performing efficiently, other metrics such as kW/ton of chilled water should be examined. See Appendix XVII for more summary information.

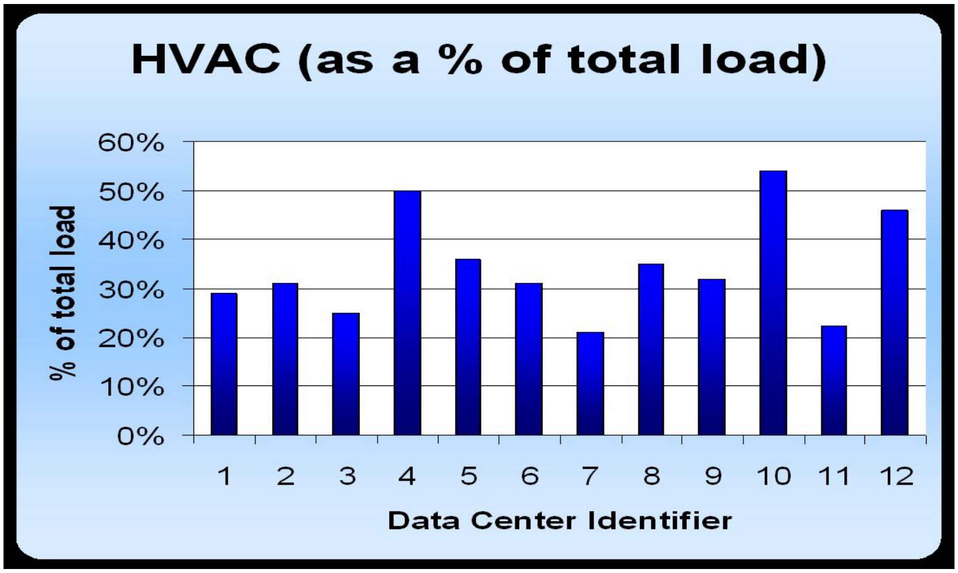


Figure 5. HVAC Load As A Percentage Of Total Load

Surprisingly, the uninterruptible power supply (UPS) devices were found to be more inefficient than expected in many of the data centers based upon typical manufacturers claims. These devices are continuously consuming between approximately 5 to 50 % of the electrical power supplied to the IT equipment (compared to a nominal 10% that might be expected based upon manufacturer's data) with a multiplying effect approximately doubling the overall effect when considering the cooling of these loads.

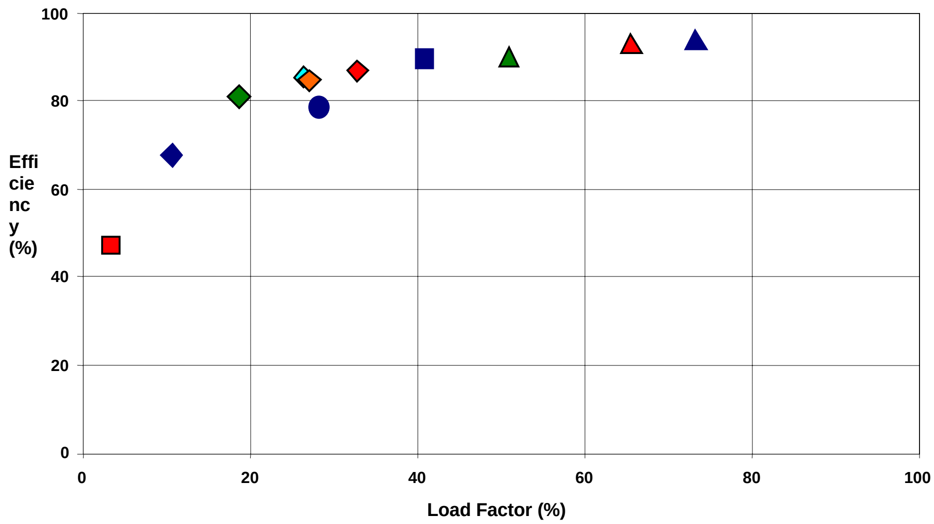


Figure 6. UPS Efficiency vs. Load Factor

Figure 6 plots the actual measured UPS efficiency and as it illustrates, the efficiency of UPS systems drop off significantly at partial loads. This situation is prevalent in data centers that were studied. Data center UPS systems are operating at much less than full load for a variety of reasons including:

- Oversized equipment
- Partially filled with IT equipment
- Compaction due to replacement of old equipment with smaller, more efficient new equipment
- Redundancy strategies

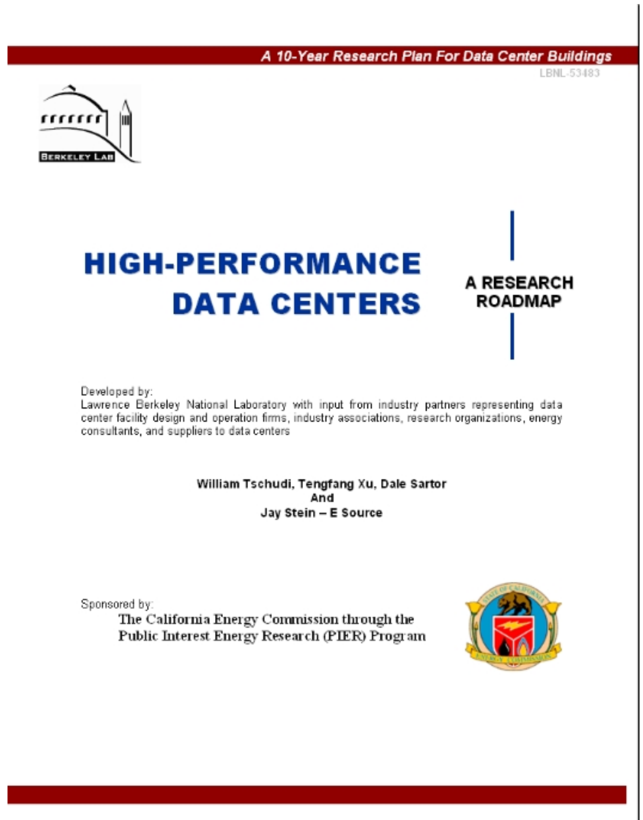
3.2. California Data Center Load Characterization

The estimates of data center floor space in California are summarized below:

Hosting Facilities	2 million SF
Corporate Facilities	2-4 million SF
Institutional Facilities	0.5-1 million SF
Educational Facilities	0.5 million SF
Total Net Data Center Floor Area in California	5-7.5 million square feet

The average total energy intensity in California data centers (based upon case studies and Uptime Institute data) is approximately 50 Watts/square ft. Therefore, the total electrical demand attributable to California data centers is estimated at between 250 and 375 MW. See Appendix I for additional information.

3.3. High-performance Data Centers – a Research Roadmap


A 10-Year Research Plan For Data Center Buildings

LBNL-53483

BERKELEY LAB

HIGH-PERFORMANCE DATA CENTERS

A RESEARCH ROADMAP

Developed by:
Lawrence Berkeley National Laboratory with input from industry partners representing data center facility design and operation firms, industry associations, research organizations, energy consultants, and suppliers to data centers

William Tschudi, Tengfang Xu, Dale Sartor
And
Jay Stein – E Source

Sponsored by:
The California Energy Commission through the Public Interest Energy Research (PIER) Program

Figure 7 High-Performance Data Centers – a Research Roadmap Report

The report entitled "High-Performance Data Centers – a Research Roadmap" was developed through extensive interface with various industry experts in data center design and operation. The topics developed were validated and prioritized through several workshops and an intensive charrette. The completed roadmap is attached as Appendix XIII and is available for download from the LBNL data center website: http://datacenters.lbl.gov/

4.0 Conclusions and Recommendations

4.1. Data Center Electrical Load Characterization

4.1.1. Conclusions

Case Studies

Measured results for the data centers studied were quite revealing. Energy intensities were much lower than common industry claims. Average energy intensity for computing equipment was measured at approximately 25 W/SF with approximately equal energy intensity required for the infrastructure to support the IT equipment. This resulted in total energy intensity of approximately 50 W/SF. A wide variation in overall intensity and in individual system efficiencies was observed suggesting that significant improvement is possible with current best practices.

Data center owners/operators were eager to participate in the case studies. They wanted to know how their facility compared to others and were very open to energy efficiency recommendations. At each of the case study sites, the energy end use in the data center was determined along with the efficiency of key systems. Although many operators track the total IT equipment load – easily read from most UPS systems – very few had information on the total end use breakdown or the efficiency of their infrastructure systems. In addition, a number of efficiency recommendations were presented and most of the building owners indicated that some of the recommendations would be explored as retrofit projects, while others would be considered for future new construction. A follow-up to investigate what was adopted and the rationale for adoption could be the focus of a future PIER investigation.

Current practice using available technologies and techniques is far from optimal. By examining the better performing systems, current best practices may be able to be identified and should be the subject of a future examination. In addition, the case studies helped to identify areas where future research could lead to further efficiency gains. These areas were included in the research roadmap for future consideration.

Many in the industry hold a belief that the rising energy and computing intensity of IT equipment will lead to inability for it to be adequately cooled by air, yet the case studies and other industry data did not support this concern at this time for the overall data center. In fact in some data centers, compaction had taken place (large inefficient computers were replaced with smaller computers having much greater computational capacity - along with higher individual intensity). But the greater computational ability of the smaller, more energy intensive IT equipment resulted in lower overall energy intensities for the data center. While it is possible that the intensities may rise as the capability of these new machines are exceeded in the future, and additional equipment is added to existing computer rooms, there is a possibility that computational ability may continue to outpace needs - resulting in a net decrease in energy intensity.

4.2. California Data Center Load Characterization

Existing market data is not sufficient to accurately quantify the overall data center market in California. Based upon the various estimation methods in this study, the California data center electrical load is estimated to be 250-375 MW based upon estimates of floor area of 5 – 7.5 million SF. See Appendix I for additional details.

4.2.1. Commercialization Potential

Not Applicable

4.2.2. Recommendations

The limited number of case studies and benchmark results currently does not provide a statistically significant data set sufficient to conclusively bound the operating characteristics of California's entire data center population. While the results do suggest that there is significant possibility for improvement, additional benchmark results will be essential in order for a comprehensive best practices summary to be developed. It is recommended that additional benchmarks be obtained through PIER efforts, self-benchmarking, and other industry sources such as utility programs or industry associations such as the Uptime Institute. By determining the best performing systems in a large sampling of data centers, the "best practices" that led to their high performance can be identified. Some of the practices are likely to be applicable to both new construction and retrofit of existing data centers, depending upon their economic viability. These best practices could then be put into guidelines for data center owners and designers, forming a basis for public interest incentive programs.

As more benchmark data are obtained and best practices developed, additional deployment activities should be pursued to present this information to the target market. Continual involvement with industry associations such as the 7x24 Exchange, the Uptime Institute, Silicon Valley Manufacturers Group, etc. will help to ensure that energy efficiency has level of "visibility" on a par with current issues such as reliability, power quality, etc.

4.2.3. Benefits to California

The case studies performed during this project have provided the data center owners with a clear understanding of their energy use and are likely to spawn energy efficiency improvement projects at the facilities that were studied. But a broader group of data center professionals were also exposed to the results of the studies through workshops and industry events. This has created increased industry awareness and has started dialogue within data center owners and designers, which will be very beneficial.

4.3. High-performance Data Centers – a Research Roadmap

4.3.1. Conclusions

A consensus from numerous industry experts contacted during the roadmapping effort was that California's data centers need to become more energy efficient to save operating costs as energy costs rise, and to improve the reliability. The California Energy crisis and the downturn in "dot com" businesses have led data center owners to investigate efficiency opportunities. Companies contacted to participate in benchmarking and case studies were eager to participate in this project. Many were actively looking for efficiency opportunities. Some expressed the opinion that electrical distribution system reliability could be improved if many of the high intensity facilities could become more efficient. In addition increasing energy costs also emphasized the need for savings. As the data center market declined, the interest level for finding efficiency opportunities remained high because improving bottom line savings was essential. This, coupled with a perception that energy intensities were reaching the limits of air-cooling generated a lot of interest in researching new approaches. There is a unique opportunity at this time to couple energy efficiency with reliability concerns.

The roadmap focused primarily on energy efficiency aspects appropriate for public interest involvement. These activities developed through industry participation represent a large portion of the overall solution but are not all that can be done. The industry continues to research new technologies in very specialized areas where public interest research would not be appropriate.

4.3.2. Commercialization Potential

Although the roadmap addresses needed research - primarily those activities suited for public interest involvement - there are a number of topics where industry must take the lead, given encouragement or where a clear market potential exists. For example, more efficient heat transfer mediums within IT equipment would need to be developed by manufacturers, however public interest programs could provide needed incentives. IT professionals and data center owners must demand improvements in key equipment and building systems such as server power supply efficiency or uninterruptible power supply efficiency. In addition public interest programs such as ENERGY STAR labeling or utility incentives could be used to encourage market transformation.

4.3.3. Recommendations

The roadmap presents a multi-year research agenda. California's PIER program should proceed with the high priority tasks identified as the most beneficial to California companies by data center industry professionals. Collaboration with other industry efforts, such as the Uptime Institute, the 7 X 24 Exchange Organization, CEETHERM, ITHERM, and ASHRAE, etc. should continue to enable as much of the roadmap to be realized as possible. To achieve the full potential in energy savings, progress on various levels is needed. Individual activities will achieve a level of improvement but attacking the overall opportunity will yield large benefits to industry and the state's electrical power industry's ability to provide adequate energy supply to meet demand. A multi-year program that provides research into the full range of topics identified in the roadmap is expected to lead to a 40-50% overall reduction in energy use.

Information technology- its equipment - and the industries that depend upon it continually change. Computing technologies change rapidly and have a profound impact on the facilities in which they are located. Consequently, the roadmap topics and their priority should be reviewed periodically. The roadmap should be considered a living document and changes in priority and technological emphasis should be made as the market needs change.

4.3.4. Benefits to California

The High Performance Data Centers research roadmap provides the PIER program with much needed understanding of how the data center industry views needed research and its priority. The PIER Industrial Program will be able to utilize the roadmap to plan a strategy to aggressively make improvements in this critical market sector. The roadmap will also facilitate collaborations with other energy research and industry organizations thereby leveraging public sector efforts in California.

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Appendices

Estimating Total Power Used By Data Centers in California:

Appendix I "Estimating Total Power Used By Data Centers in California"; Jonathan G. Koomey, Osman Sezgen, and Robert Steinmetz, 2003

Data Center Case Studies:

Appendix II. "Data Center Energy Characterization Study, Facility 1"; PG&E Case Study; Rumsey Engineers, Inc., 2001

Appendix III. "Data Center Energy Characterization Study, Facility 2"; PG&E Case Study, Rumsey Engineers, Inc., 2001

Appendix IV. "Data Center Energy Characterization Study, Facility 3"; PG&E Case Study, Rumsey Engineers, Inc., 2001

Appendix V. "Data Center Energy Benchmarking Case Study, Facility 4"; Federal Data Center Facility, Rumsey Engineers, Inc.; LBNL - TengFang Xu, 2003

Appendix VI. "Data Center Energy Benchmarking Case Study, Facility 5"; Federal Data Center Facility, Rumsey Engineers, Inc.; LBNL - TengFang Xu, 2003

Appendix VII. "Data Center Energy Benchmarking Case Study, Facility 6"; PIER Project, Rumsey Engineers, Inc.; LBNL – William Tschudi, 2003

Appendix VIII. "Data Center Energy Benchmarking Case Study, Facility 7"; PIER Project, Rumsey Engineers, Inc.; LBNL – William Tschudi, 2003

Appendix IX. "Data Center Energy Benchmarking Case Study, Facility 8"; PIER Project, Rumsey Engineers, Inc.; LBNL – William Tschudi, 2003

Appendix X. "Data Center Energy Benchmarking Case Study, Facility 9"; PIER Project, Rumsey Engineers, Inc.; LBNL – William Tschudi, 2003

Appendix XI. "NY Data Center Energy Benchmarking and Case Study, Facility 10"; NYSERDA Case Study, Syska & Hennessy; LBNL – William Tschudi, 2003

Appendix XII. "NY Data Center Energy Benchmarking and Case Study, Facility 11"; NYSERDA Case Study, Syska & Hennessy; LBNL – William Tschudi, 2003

High-Performance Data Centers – a Research Roadmap

Appendix XIII - "High-Performance Data Centers – a Research Roadmap", Lawrence Berkeley National Laboratory Report No. 53483

Appendix XIV - RMI Charrette brochure, attendee list, and report.

Appendix XV - 8-22-02 Workshop Agenda, presentation, and meeting summary

Appendix XVI - 10-16-02 Workshop meeting notice and presentation

Appendix XVII - 4-17-03 Meeting notice and presentation

ACEEE Paper

Appendix XVIII – ACEEE 2003 paper #162, "Data Centers and Energy Use – Let's Look at the Data"

Appendix XIX – Annotated Bibliography

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